Lightning Interaction with Tall Structures

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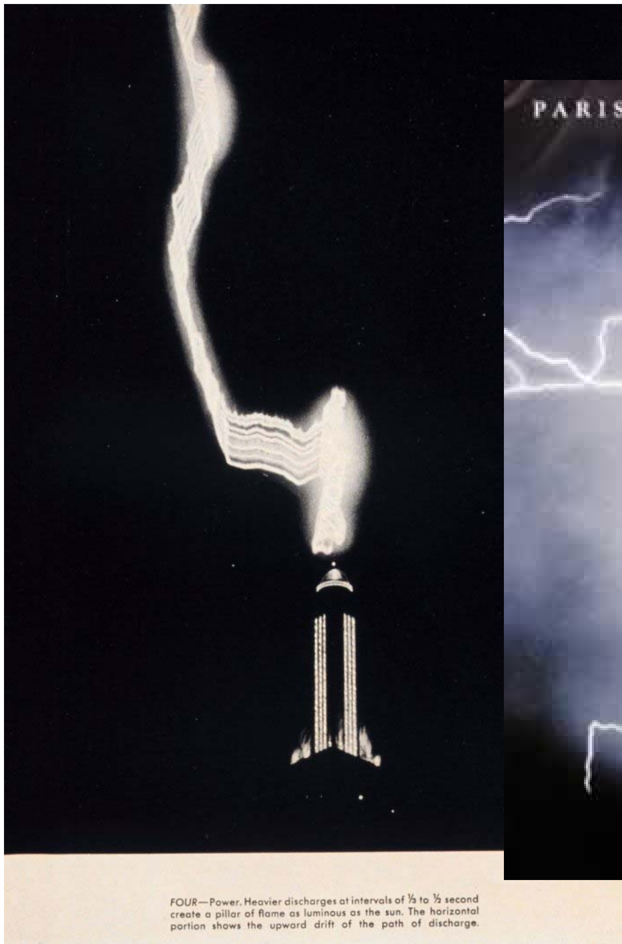
Outline

- Introduction
- Influence of tall structure on incidence of lightning
- Modeling lightning strikes to tall structures for field computation
- Tower Enhancement / Attenuation of the electromagnetic field
- Lightning protection of communication towers
- Conclusions

Introduction

- Tall structures are often struck by lightning

Introduction



Introduction

- Tall structures are often struck by lightning
- Tall towers are a means to record lightning currents

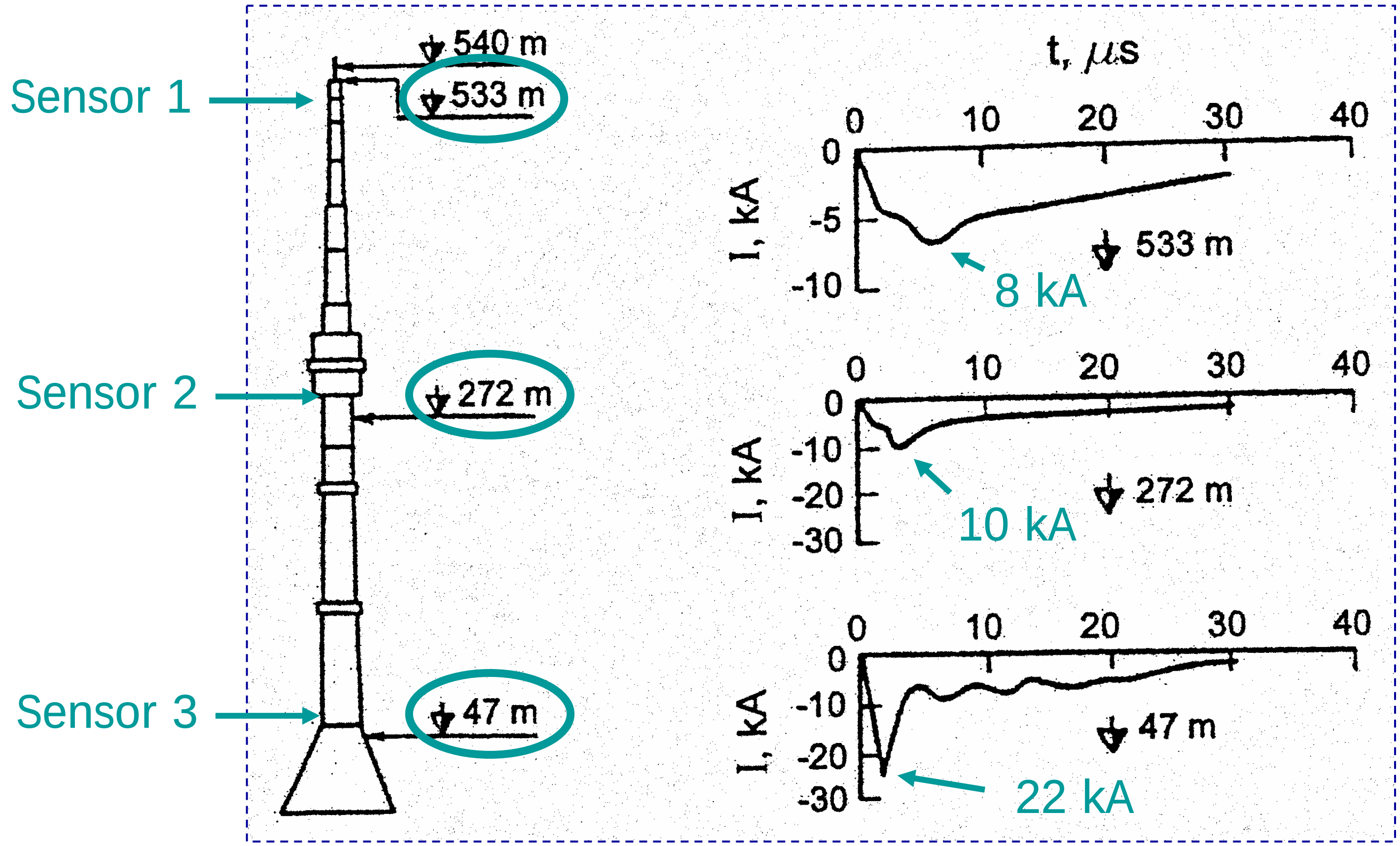
Introduction

Introduction

- Tall structures are often struck by lightning
- Tall towers are a means to record lightning currents
- Transient processes may occur along the tower

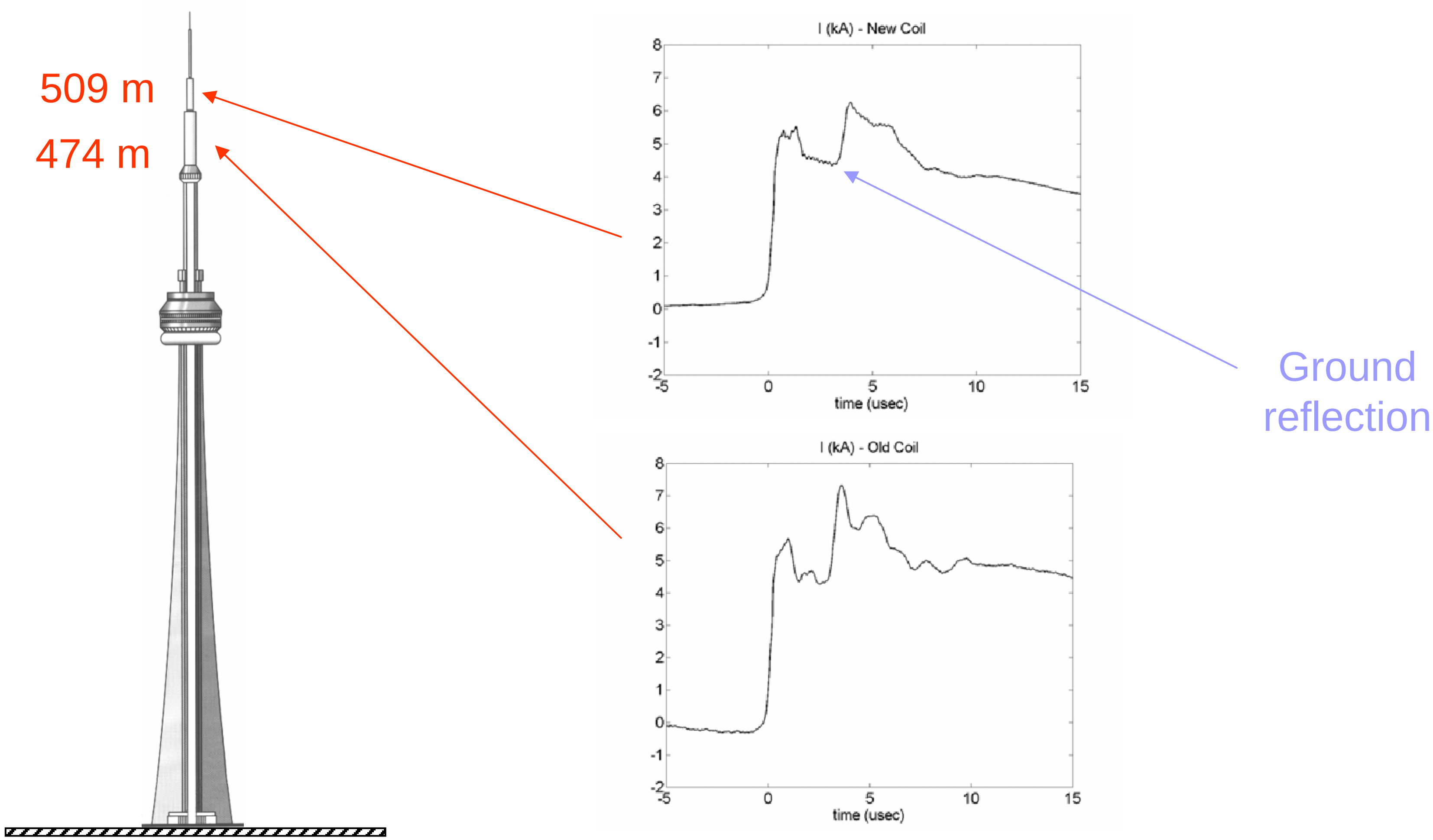
Data from Tall Towers:

Return Stroke Current Measured along The Ostankino Tower

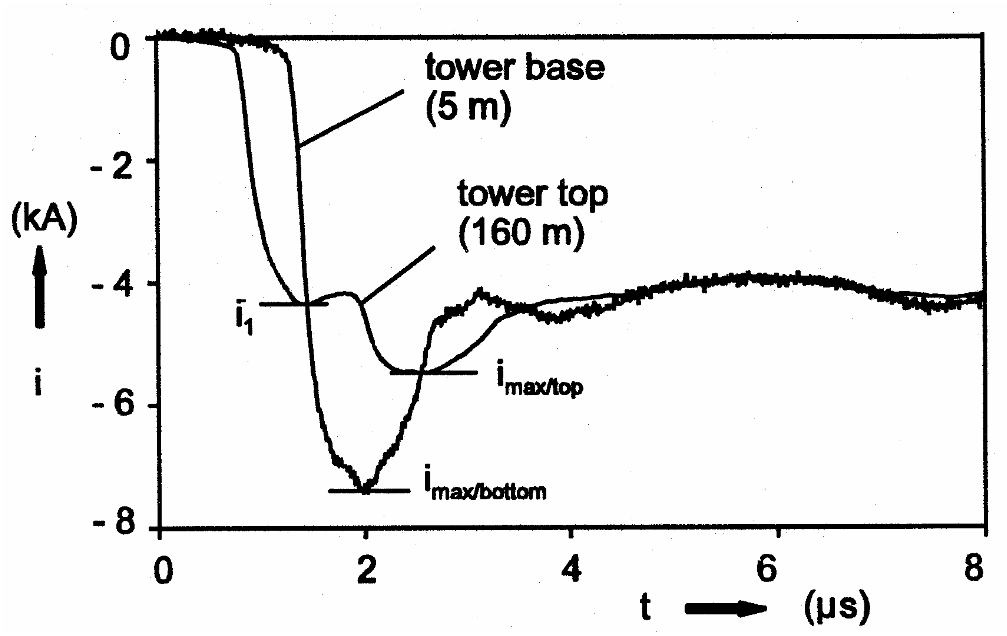


From Rakov, 2001

Data from Tall Towers:
Return Stroke Current Measured along The CN Tower



Data from Tall Towers:
Return Stroke Current Measured along Peissenberg Tower



From Heidler

Introduction

- Tall structures are often struck by lightning
- Tall towers are a means to record lightning currents
- Transient processes may occur along the tower
- EM environment is influenced by the presence of the tower
- Data from instrumented towers can be used to calibrate LLS

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Incidence of Lightning to Tall Structures

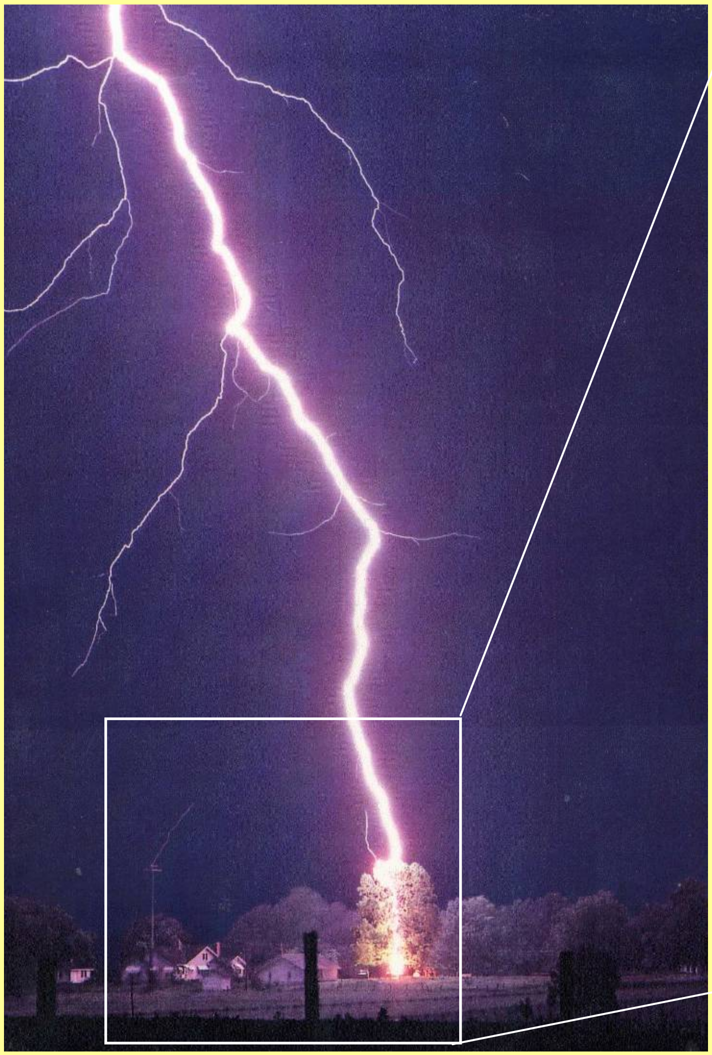
- Tall objects experience both downward and upward flashes
- The proportion is a function of height

Incidence of Lightning to Tall Structures

St Michael's Cemetery, Toronto

Leon Konigsthal, Jr. Summer 1990

Incidence of Lightning to Tall Structures

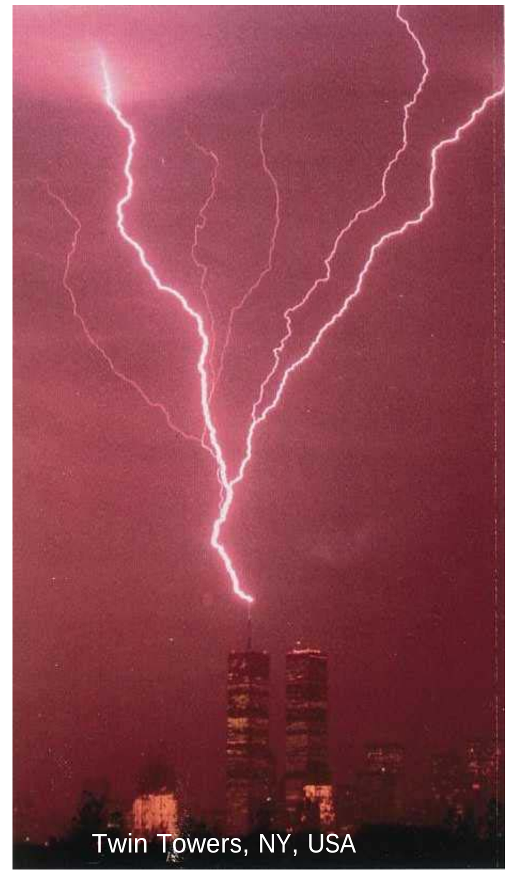


Mostly Down (to short objects)

Incidence of Lightning to Tall Structures

- Mostly upward to tall objects

Lightning strikes to the Tappi Wind Park, Tsugaru
Tohoku Electric Power Co.



Twin Towers, NY, USA

Incidence of Lightning to Tall Structures

- Not always attached to the tip!

Incidence of Lightning to Tall Structures

- Eriksson (1987) proposed the following equation for the annual lightning incidence (including both downward and upward flashes)

$$N = 24 \times 10^{-6} H_s^{2.05} N_g$$

where H_s is the object height (m), N_g is the ground flash density in $km^2 yr^{-1}$.

Incidence of Lightning to Tall Structures

- Percentage of upward flashes (Eriksson and Meal, 1984) :

$$P_u = 52.8\ln(H_s) - 230 \qquad 78 < H_s < 518$$

Incidence of Lightning to Tall Structures

- Downward lightning incidence to a structure:

$$N_d = A \cdot N_g$$

where *A* is the equivalent attractive area

- For a tall object, *A* is given in terms of the equivalent attractive radius R_a

$$A = \pi R_a^2 \quad , \quad R_a = \alpha H_s^\beta$$

where α and β are empirical constants
(CIGRE: α=14, β=0.6)

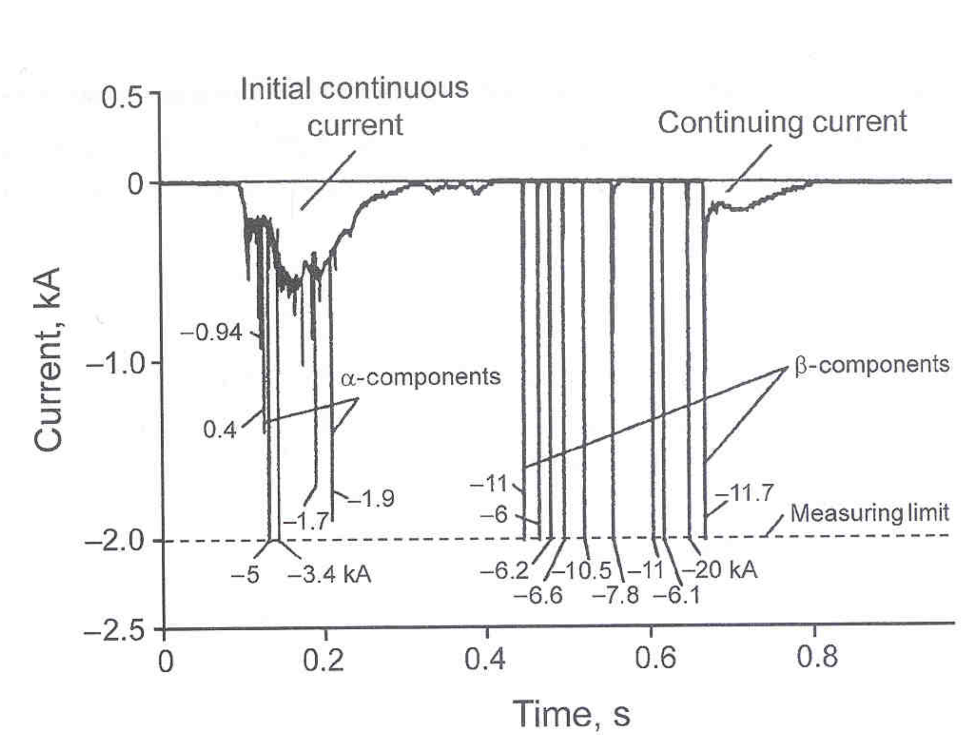
Incidence of Lightning to Tall Structures

- Upward lightning incidence to a structure:

$$N_u = N - N_d$$

- For structure heights of <100 m, $N_u \cong 0$
- For structure heights of > 500, $N_d \cong 0$

Typical Current record



Peissenberg Tower, Germany (Fuchs et al.)
Record clipped at -2 kA

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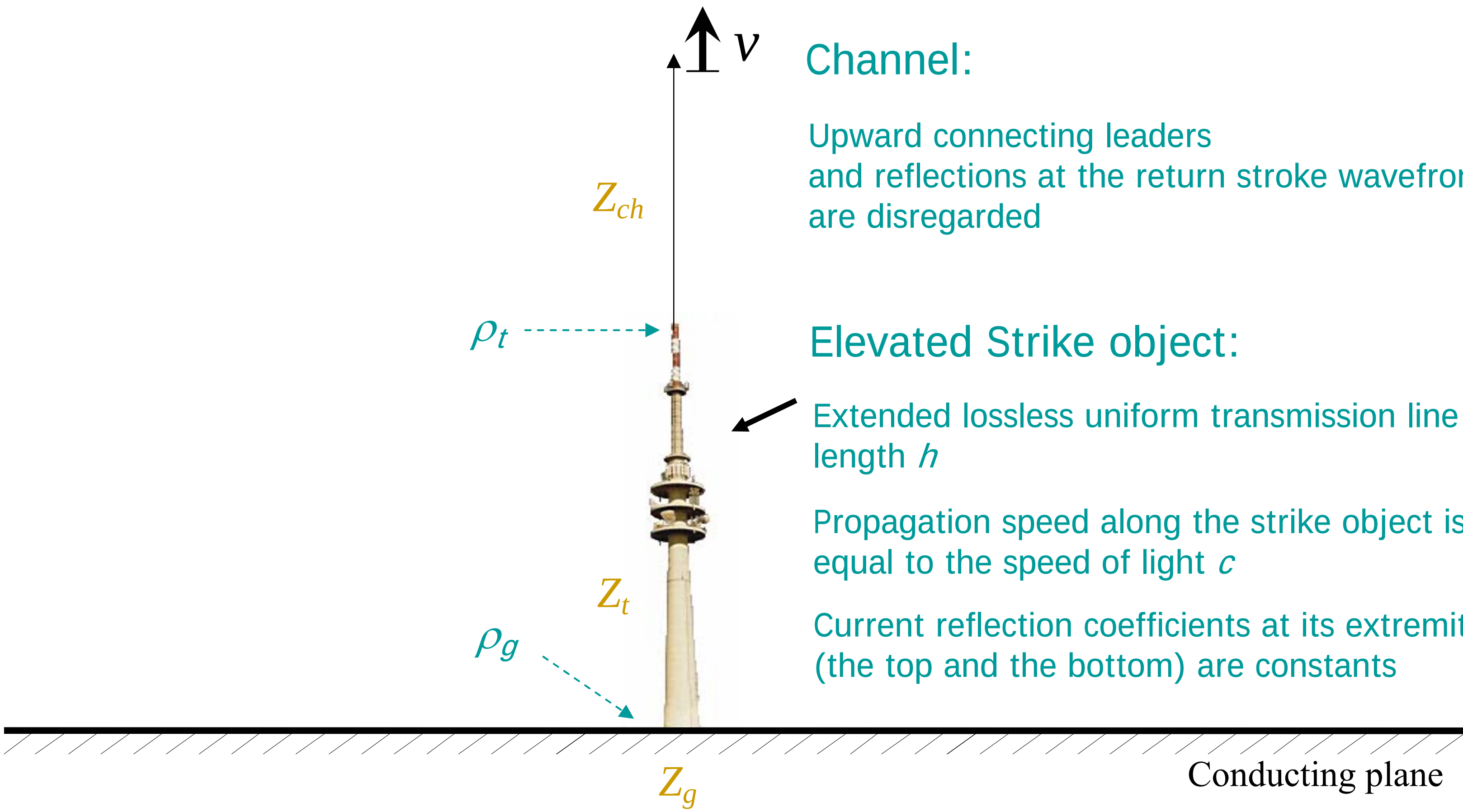
Modeling Lightning Strikes to Tall Structures

- Antenna Theory Models
  - Return stroke channel and tall structures modeled as antennas fed by a voltage (current) source
- Engineering Models
  - Current pulse associated with the return-stroke process is injected at the lightning attachment point both into the strike object and into the lightning channel
  - Distributed-source representation (consistent treatment of the impedance discontinuity at the tower top)
  - Lumped-voltage/lumped-current source representation
- Hybrid-Type Models
  - EM and circuit theory approaches

Engineering Models: Elevated Strike Object



Channel:

Upward connecting leaders and reflections at the return stroke wavefront are disregarded

Elevated Strike object:

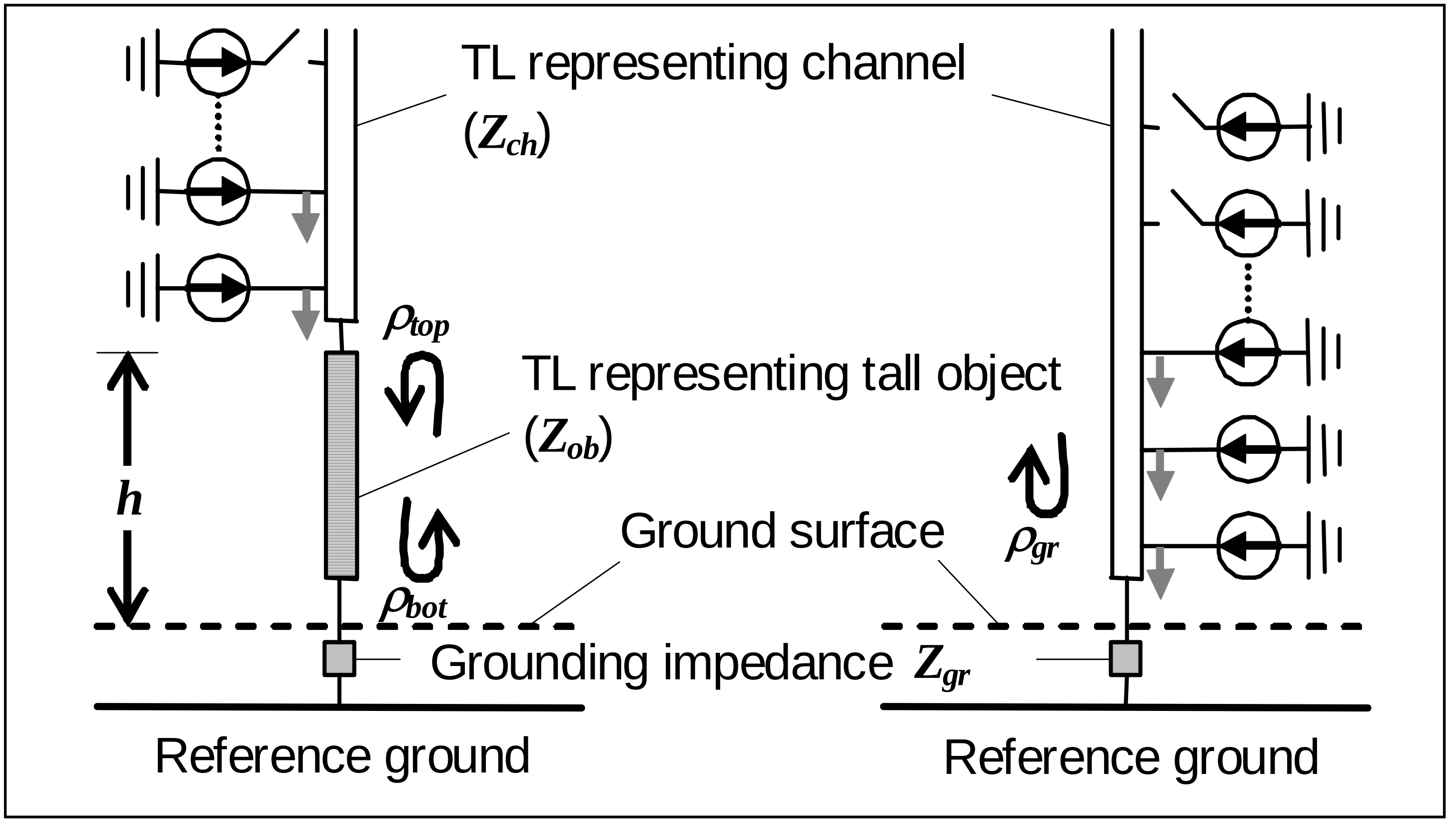
Extended lossless uniform transmission line of length *h*

Propagation speed along the strike object is equal to the speed of light *c*

Current reflection coefficients at its extremities (the top and the bottom) are constants

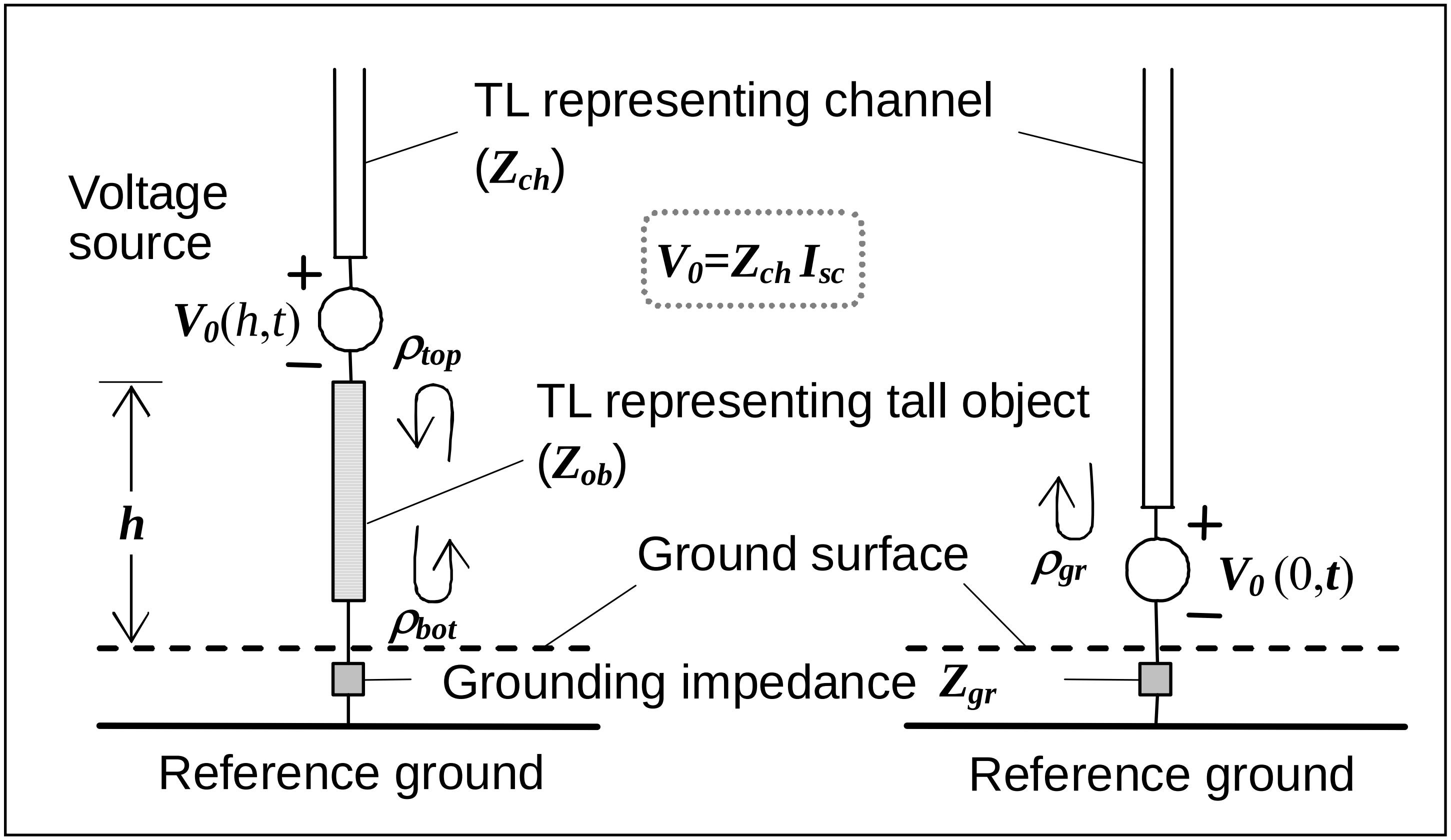
Tower Effects on EM Fields

Models of Lightning Strikes (*Rachidi et al.*, 2002)



Tower Effects on EM Fields

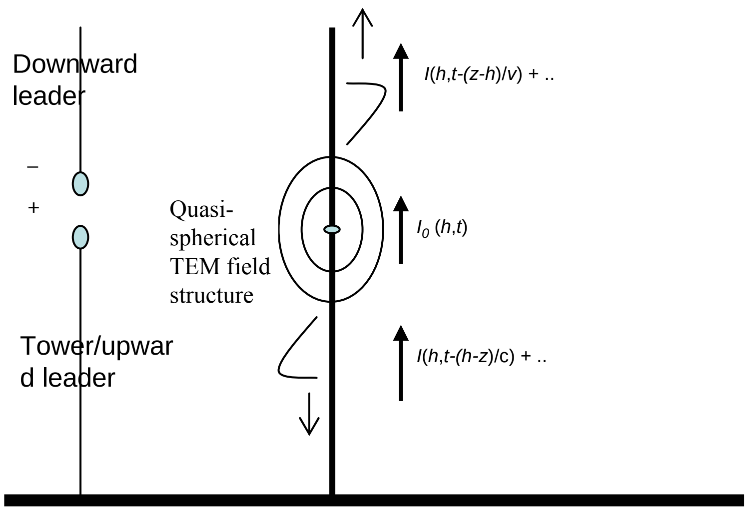
Models of Lightning Strikes *(Baba & Rakov,* 2005)

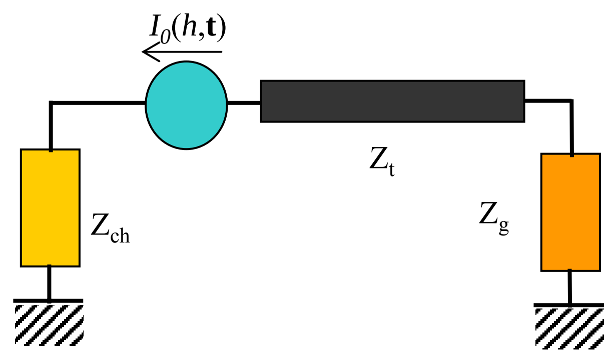


Tower Effects on EM Fields

Models of Lightning Strikes

(Thottappillil & Theethayi, 2006)





Tower Effects on EM Fields

Current Distributions

Lightning strike to a tall object

$$I(z',t)=\frac{1-\rho_{top}}{2}\sum_{n=0}^{\infty}\left[\rho_{bot}{}^{n}\rho_{top}{}^{n}I_{sc}\left(h,t-\frac{h-z'}{c}-\frac{2nh}{c}\right)+\rho_{bot}{}^{n+1}\rho_{top}{}^{n}I_{sc}\left(h,t-\frac{h+z'}{c}-\frac{2nh}{c}\right)\right]$$

along the tall object $(0\le z'\le h)$

$$I(z',t)=\frac{1-\rho_{top}}{2}\left[I_{sc}\left(h,t-\frac{z'-h}{v}\right)+\sum_{n=1}^{\infty}\rho_{bot}{}^{n}\rho_{top}{}^{n-1}\left(1+\rho_{top}\right)I_{sc}\left(h,t-\frac{z'-h}{v}-\frac{2nh}{c}\right)\right]$$

along the lightning channel $(z'\ge h)$

(Rachidi et al. 2002; Baba & Rakov 2005)

Lightning strike to flat ground

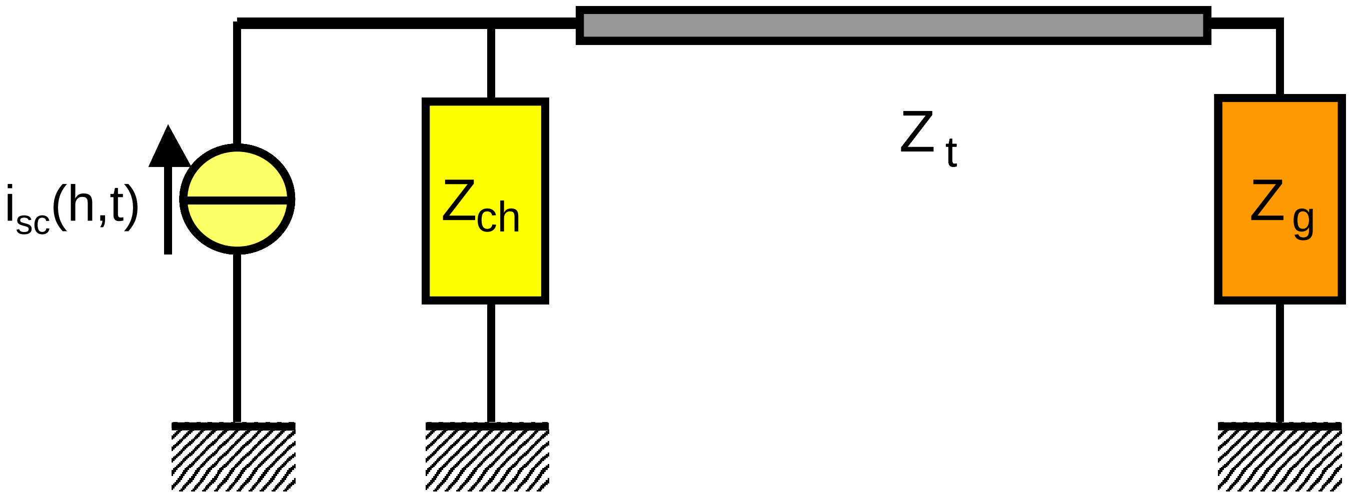
$$I\left(z',t\right)=\frac{1+\rho_{gr}}{2}I_{sc}\left(0,t-\frac{z'}{v}\right)$$

along the lightning channel $(z'\ge 0)$

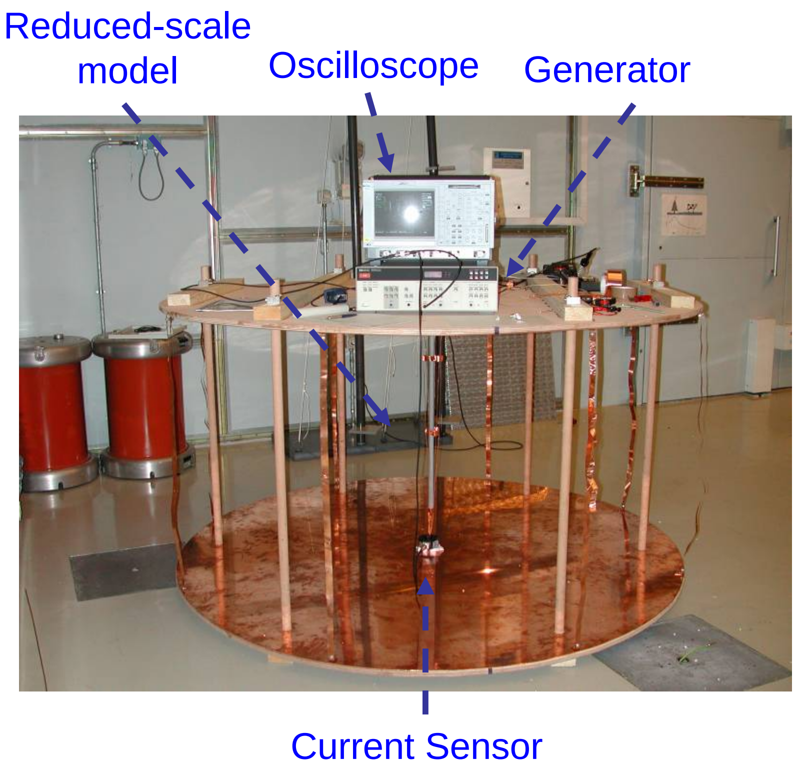
$$I_{sc}=2I_{0}$$

Engineering Models

- Equivalent circuit for the tower (struck by lightning)



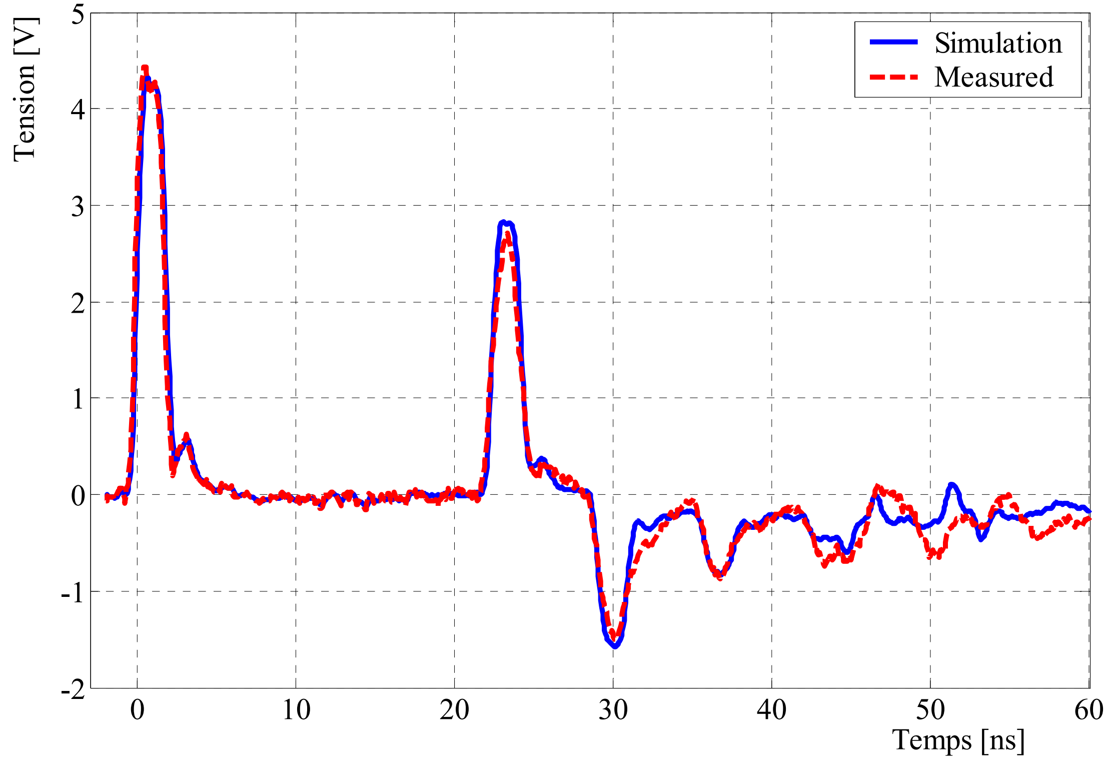
On TL Representation of Strike Objects



CN Tower Reduced-Scale Model

Bermudez et al., 2003

On TL Representation of Strike Objects



Bermudez et al., 2003

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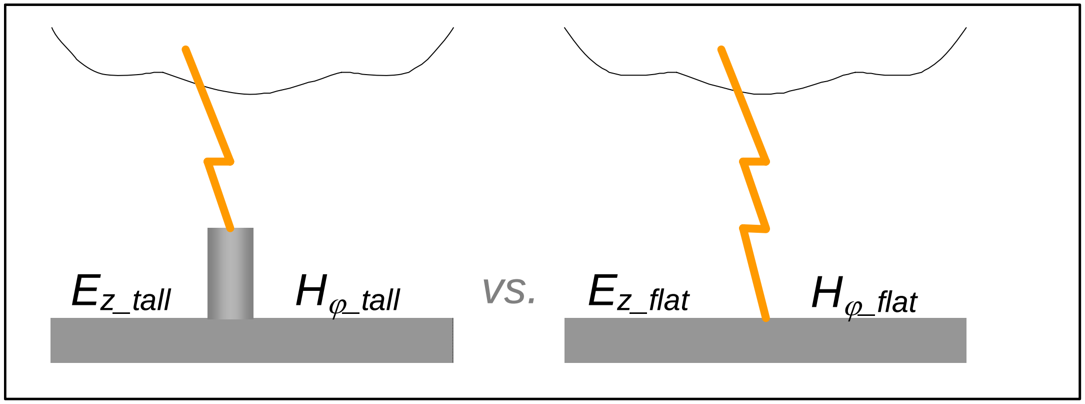
Tower Effects on EM Fields

Are $\boldsymbol{E_z}$ and $\boldsymbol{H_\varphi}$ ***enhanced*** or ***reduced***
by the presence of ***a tall strike object*** ?

How are $\boldsymbol{E_{z\_tall}} / \boldsymbol{E_{z\_flat}}$ and $\boldsymbol{H_{\varphi\_tall}} / \boldsymbol{H_{\varphi\_flat}}$
Influenced by ***return-stroke speed v***,
current risetime RT, and
structure height h ?



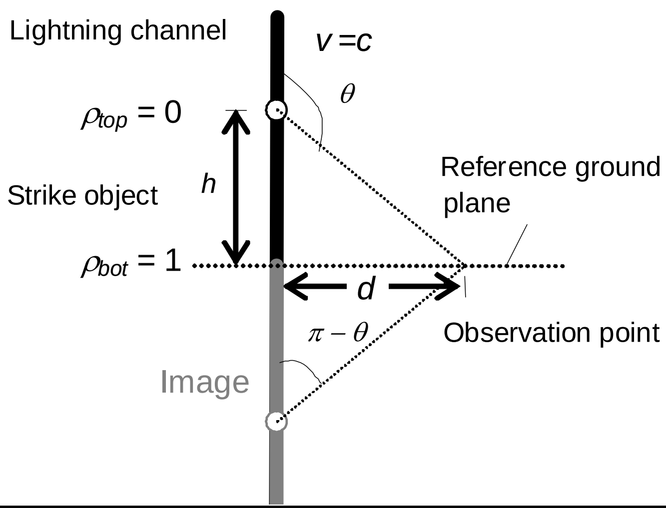
Tower Effects on EM Fields

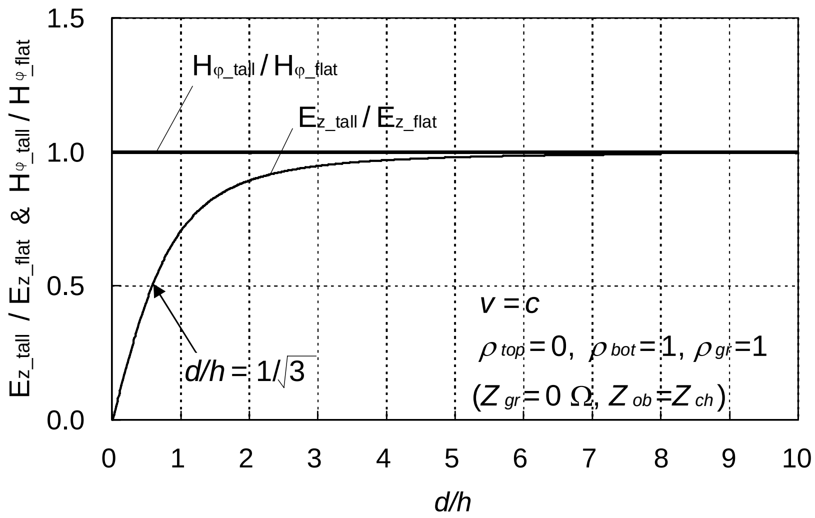
Influence of a Tall Strike Object

***An ideal condition*: *v=c*, ρ_{top}=0 ($Z_{ch}=Z_{ob}$), ρ_{bot}=1 ($Z_{gr}=0$)**

$$\frac{E_{z\_tall}(d,t)}{E_{z\_flat}(d,t)} = \frac{d}{\sqrt{d^2+h^2}} = \frac{d/h}{\sqrt{(d/h)^2+1}} \leq 1$$

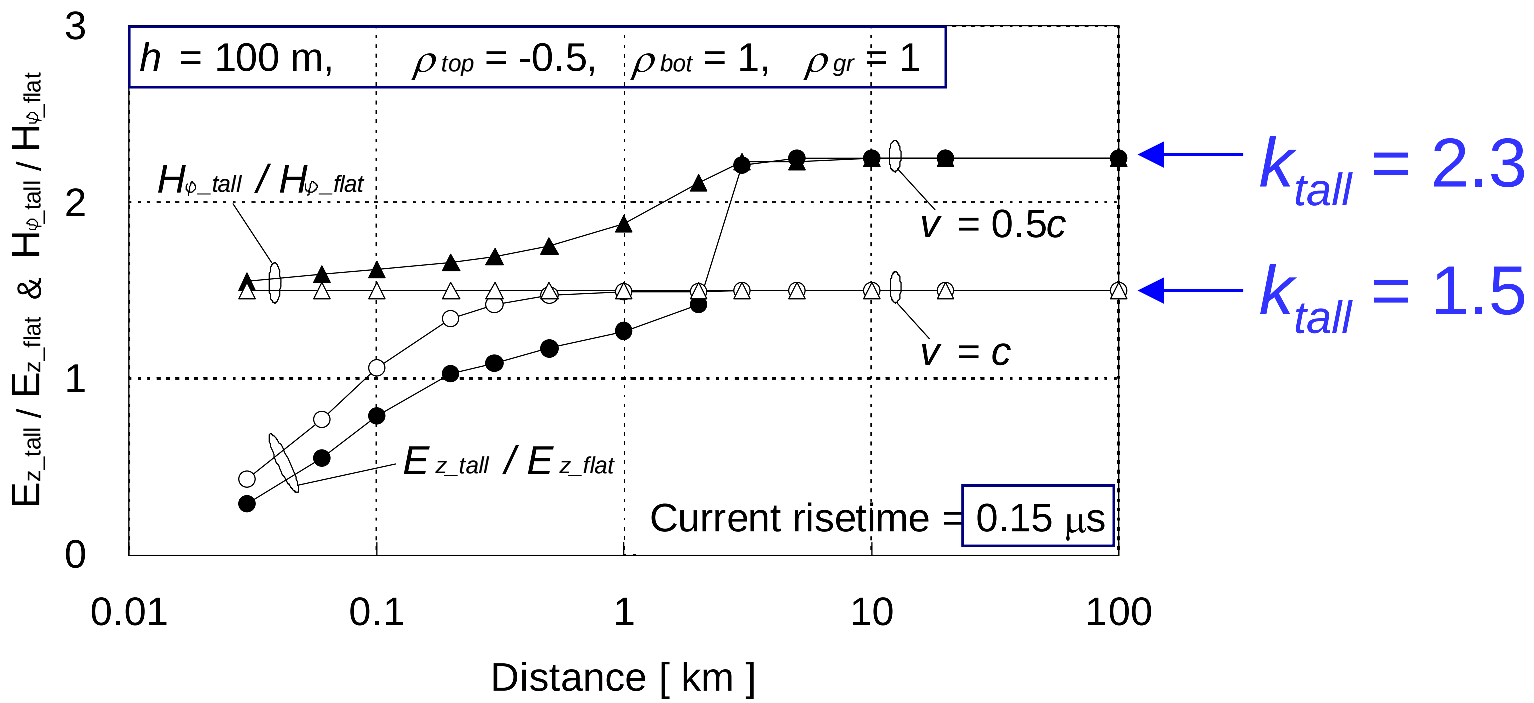
$$\frac{H_{\varphi\_tall}(d,t)}{H_{\varphi\_flat}(d,t)} = 1$$





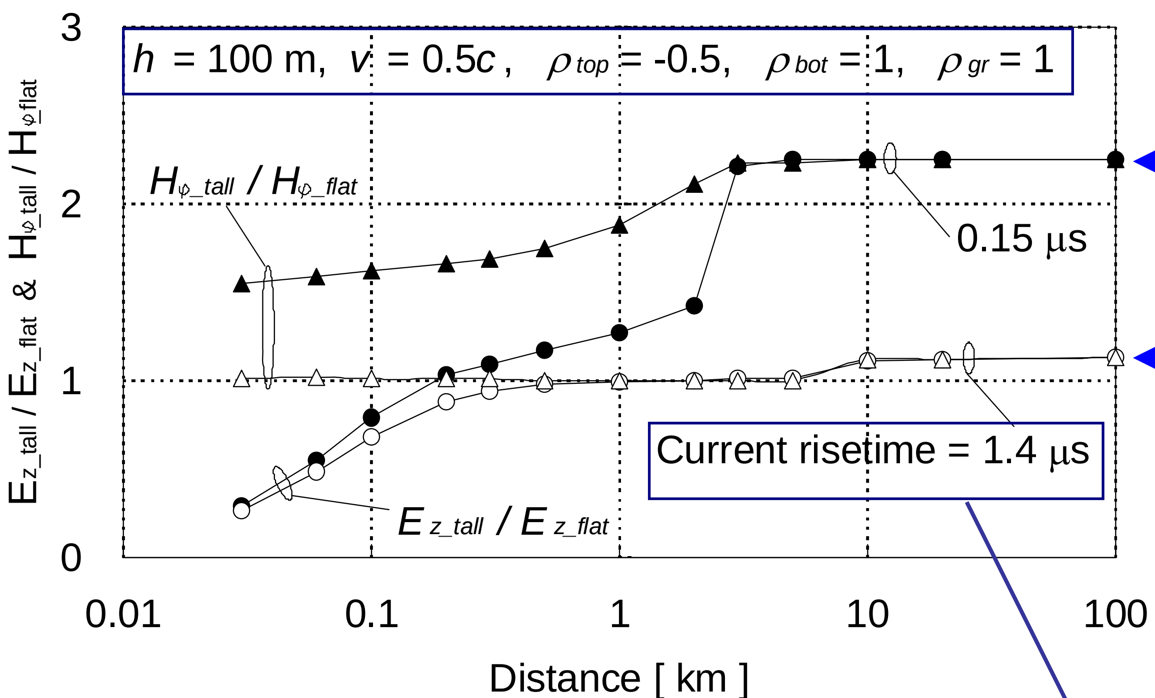
Tower Effects on EM Fields

Influence of return-stroke speed, v



Tower Effects on EM Fields

Influence of current risetime, RT



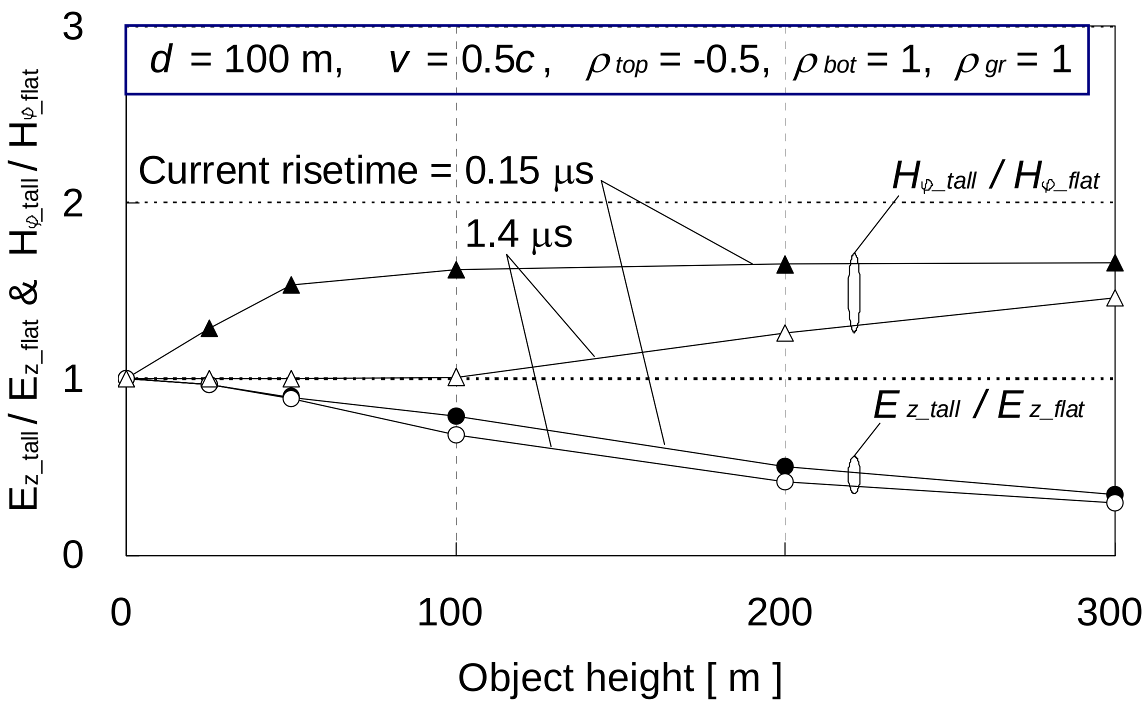
$k_{tall} = 2.3$

$k_{tall} \neq 2.3$

RT > *h*/*c*=0.33 µs

Tower Effects on EM Fields

Influence of strike object height, h



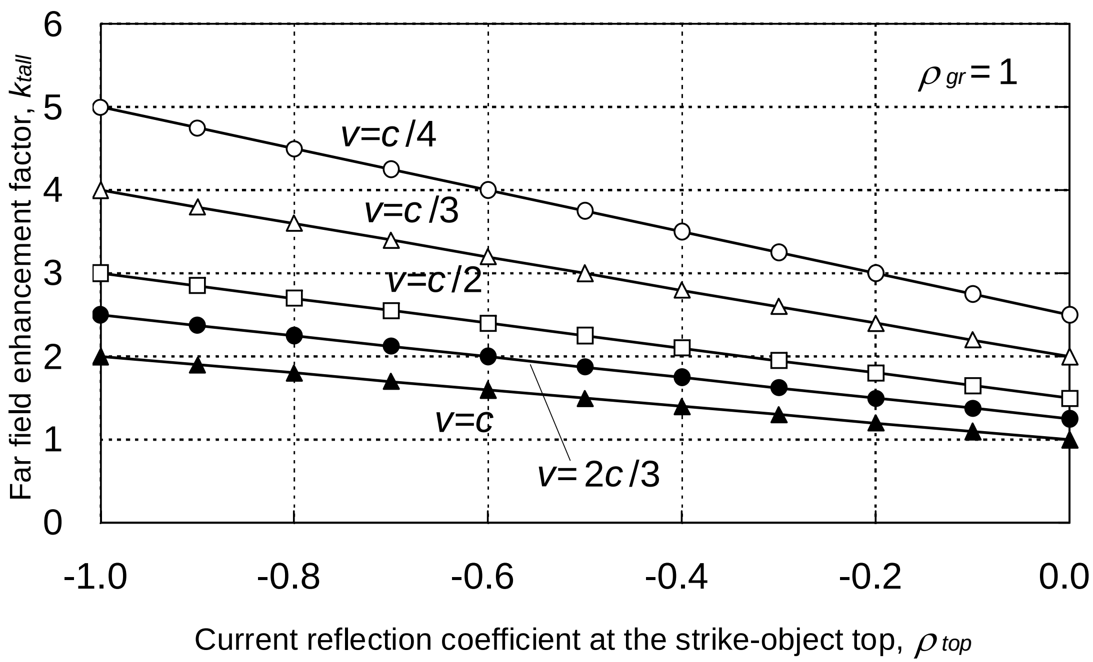
Tower Effects on EM Fields

Far Field Enhancement Factor, k_{tall}

$$k_{tall} = \frac{E_{z\_tall}}{E_{z\_flat}} = \frac{H_{\varphi\_tall}}{H_{\varphi\_flat}}$$

$$= \frac{\left(1-\rho_{top}\right)\left(\frac{c}{v}+1\right)}{\left(1+\rho_{gr}\right)}$$

$$\left(RT < h/c = 0.33\ \mu s\right)$$



Tower Effects on EM Fields

Summary of Tower Effects on EM Fields

- Owing to the presence of a tall strike object, E_z is reduced roughly within the distance $d < h$ and enhanced beyond it.
- H_φ is enhanced at any distance.
- E_{z_tall} / E_{z_flat} and $H_{\varphi\_tall} / H_{\varphi\_flat}$ increase with increasing d, and decreasing RT.
- In the vicinity of a strike object, E_{z_tall} / E_{z_flat} increases with decreasing h, while H_{φ_tall} increases with increasing h.
- Beyond several km, E_{z_tall} / E_{z_flat} becomes insensitive to d and equal to $H_{\varphi\_tall} / H_{\varphi\_flat}$. Both are given by $k_{tall}=(1-\rho_{top})(c/v+1)/(1+\rho_{gr})$.

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Lightning Protection of Communication Towers

Are lightning protection methods for protecting communication equipments sufficient to prevent lightning surge transfer to near by local networks?

Outline

- Statement of the problem
- Role of grounding
- Role of follow-on ground wire

The problem

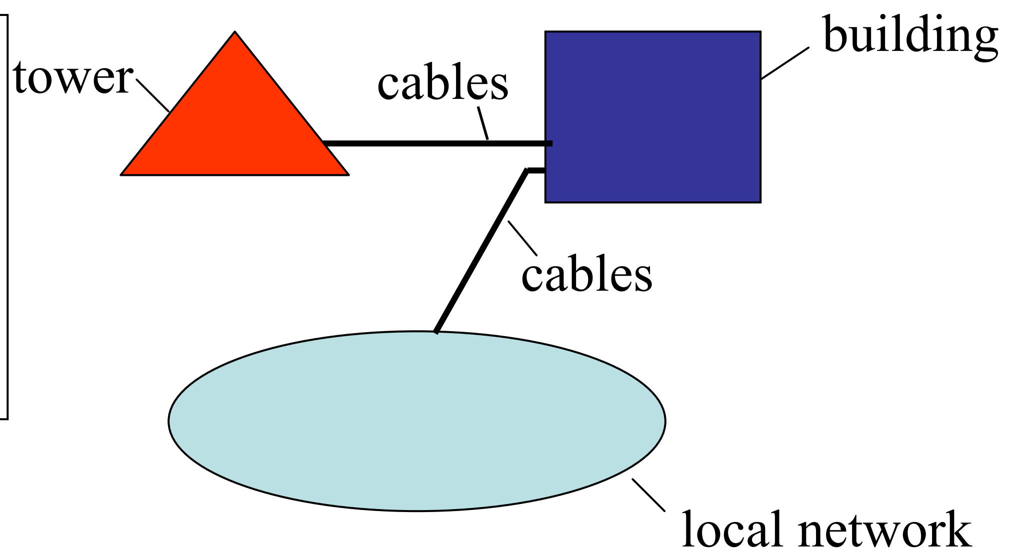
Tower: 20-200 m high

Tower-building: 0 to 20 m

Building-local network: 10 to 1000 m

High resistivity soil: ~5000 Ωm

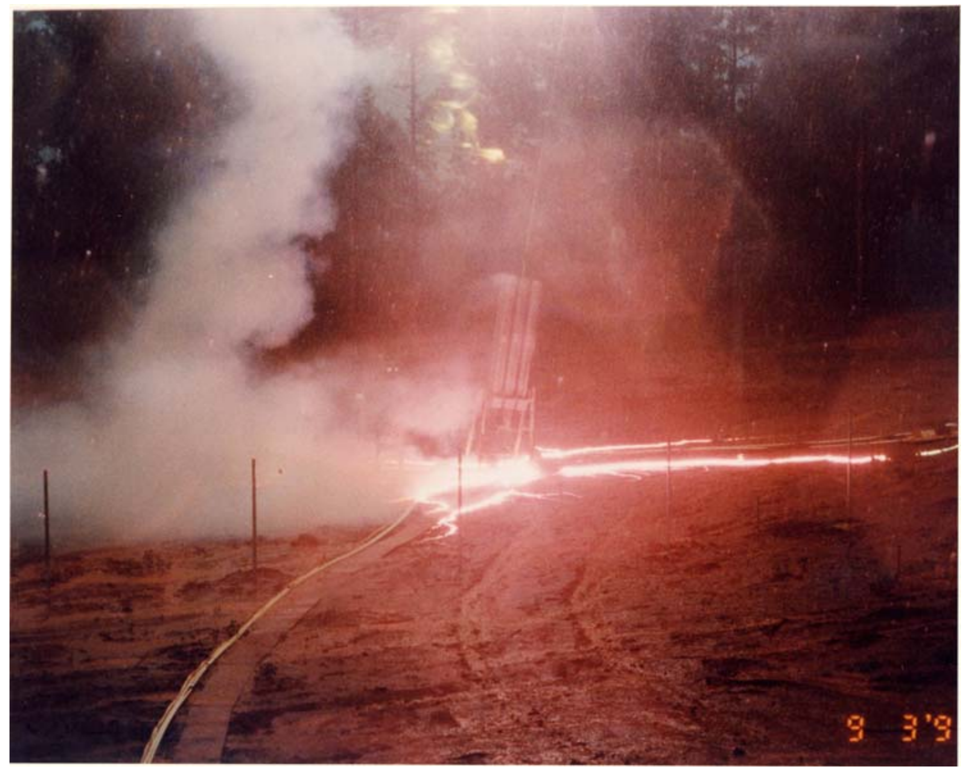
Potential rise at the tower-building complex may drive large currents via cable shields to local power network



The problem

Surface arcing in triggered lightning

Potential rise tends to drive lightning currents in all directions



Acknowledgement: Fischer, Sandia National Labs, USA

Grounding of Communication Tower Complex

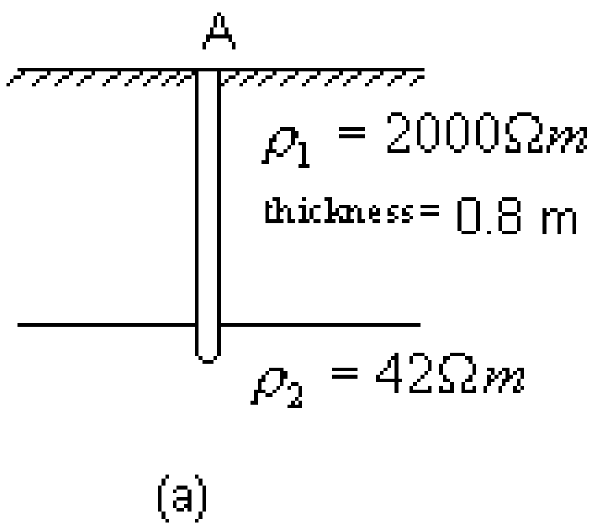
- **Purpose of Grounding**
  - Protecting assets
  - Protection from personal injury
- **Functions of grounding**
  - Dissipate lightning current to bulk earth
  - Reduce potential differences between parts

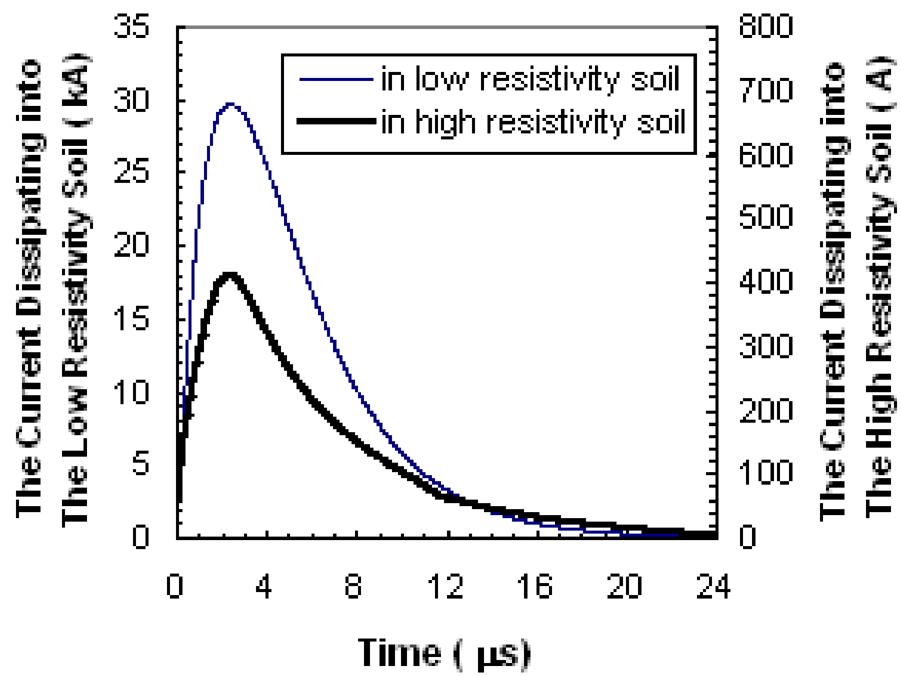
Factors Influencing Current Dissipation to Earth

- Soil resistivity
- Ionization and arcing
- Geometry of ground conductors
- Vertical vs Horizontal conductors (Remote earthing)

Soil Resistivity

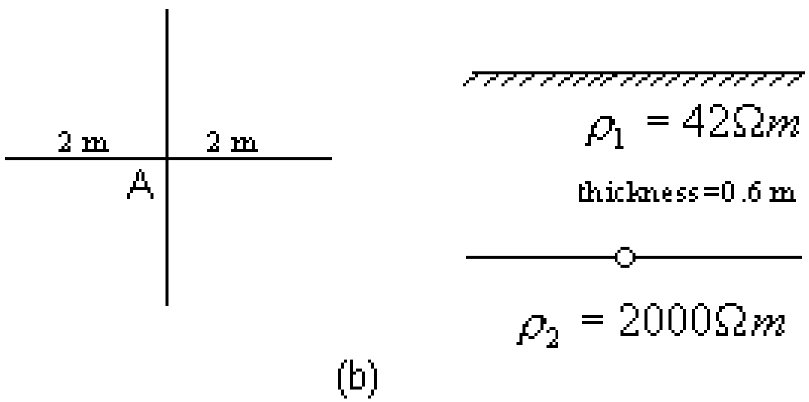
(Factors influencing current dissipation to earth)

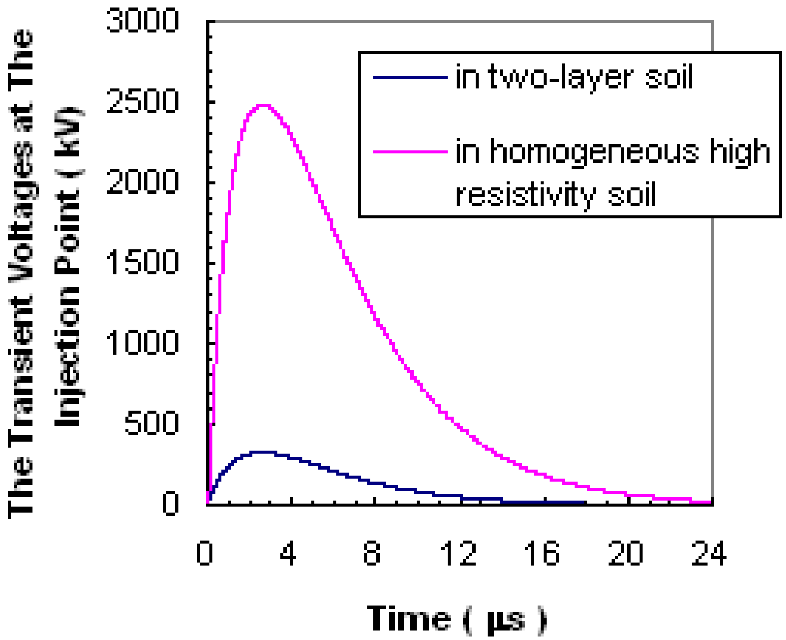




Soil Resistivity

(Factors influencing current dissipation to earth)





Ionization and Arcing

(Factors influencing current dissipation to earth)

- Both reduce grounding resistance
- Important in high resistivity soil
- Arcing inside soil and on surface
- Uncontrolled arcing not desirable
- 90% of RS above 15 kA produce surface arcing in 500 Ωm clay
- Up to 200 m long surface arcing

Geometry of Ground Conductors

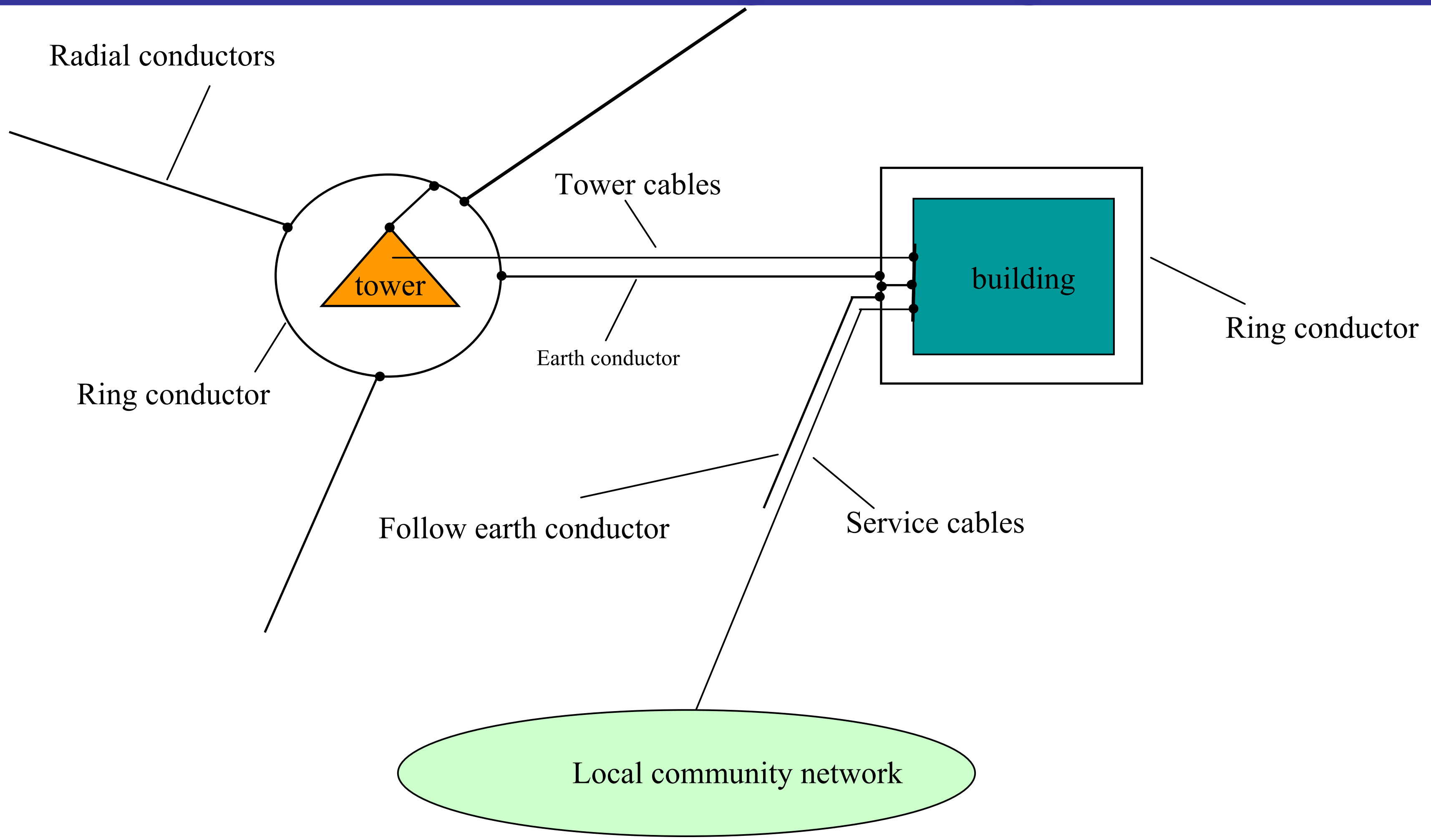
(Factors influencing current dissipation to earth)

- Number of parallel paths for current
- Length of conductor
- On the surface or buried
- Corrosion resistance

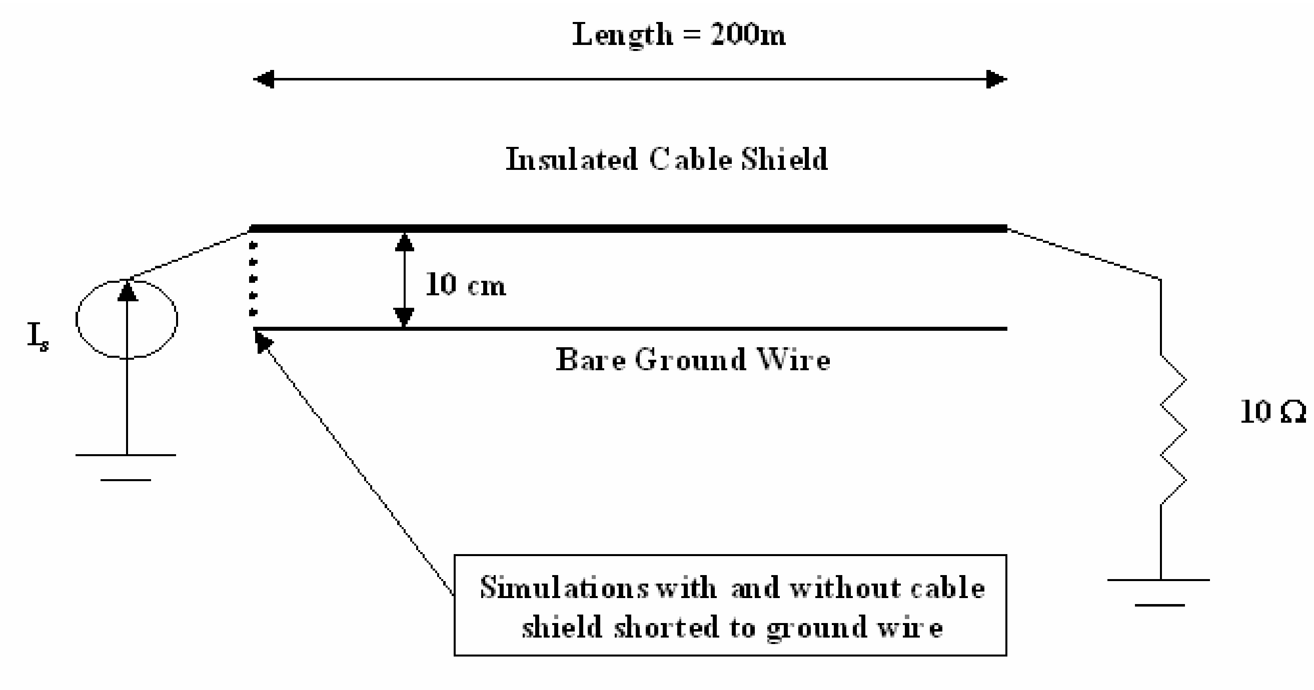
Other Factors Influencing Current Dissipation to Earth

- **Vertical verses horizontal conductors**
  - Choice depend on several factors
  - Often best results achieved by a combination
- **Grounding on rock**
  - Drilling holes or burying costly
  - Resistivity 10000 and 50000 Ωm
  - Use of fissures in the rock
  - ‘Remote’ earthing

Schematic of One Grounding Design



Reduction of Service Cable Shield Current - Modelling



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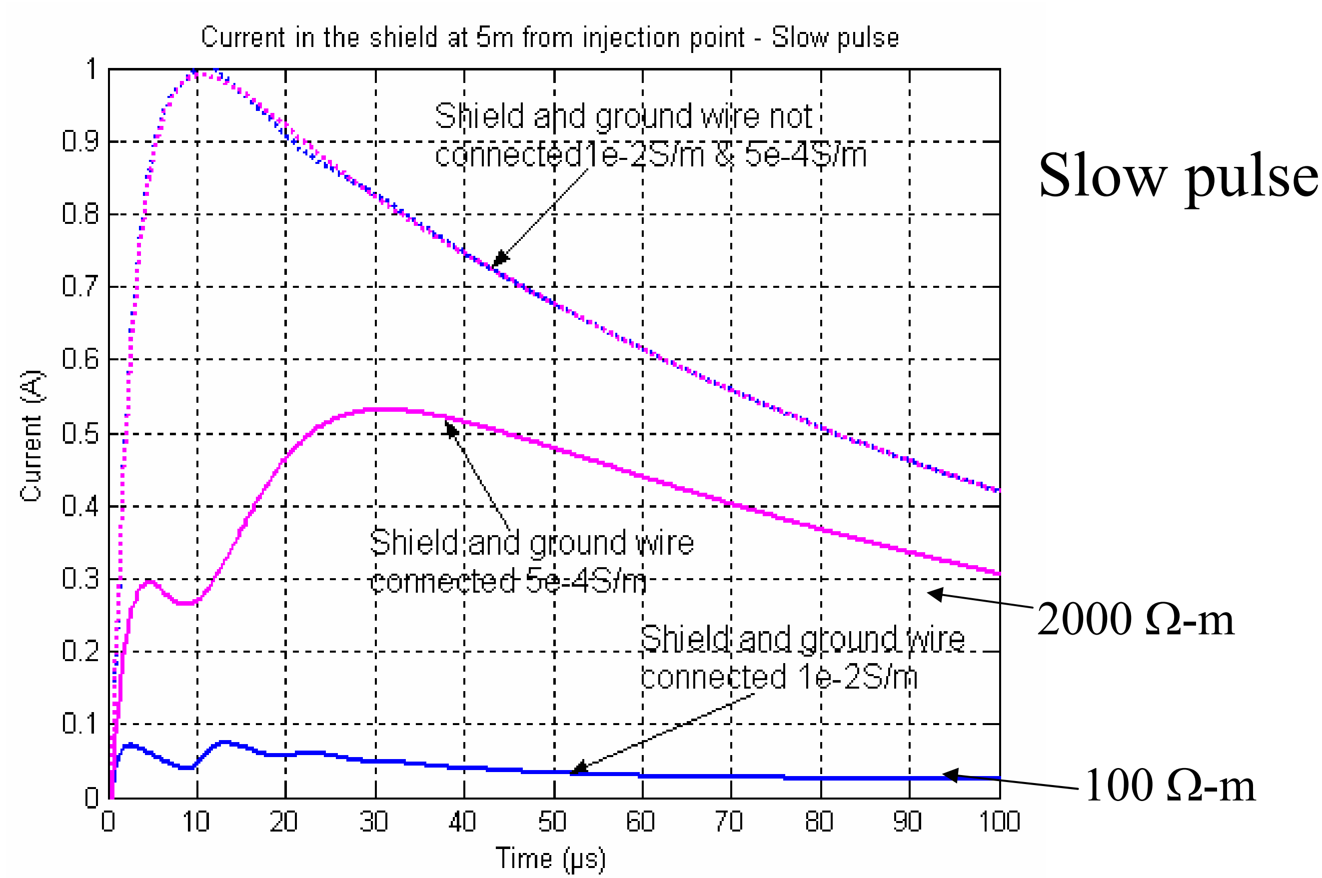

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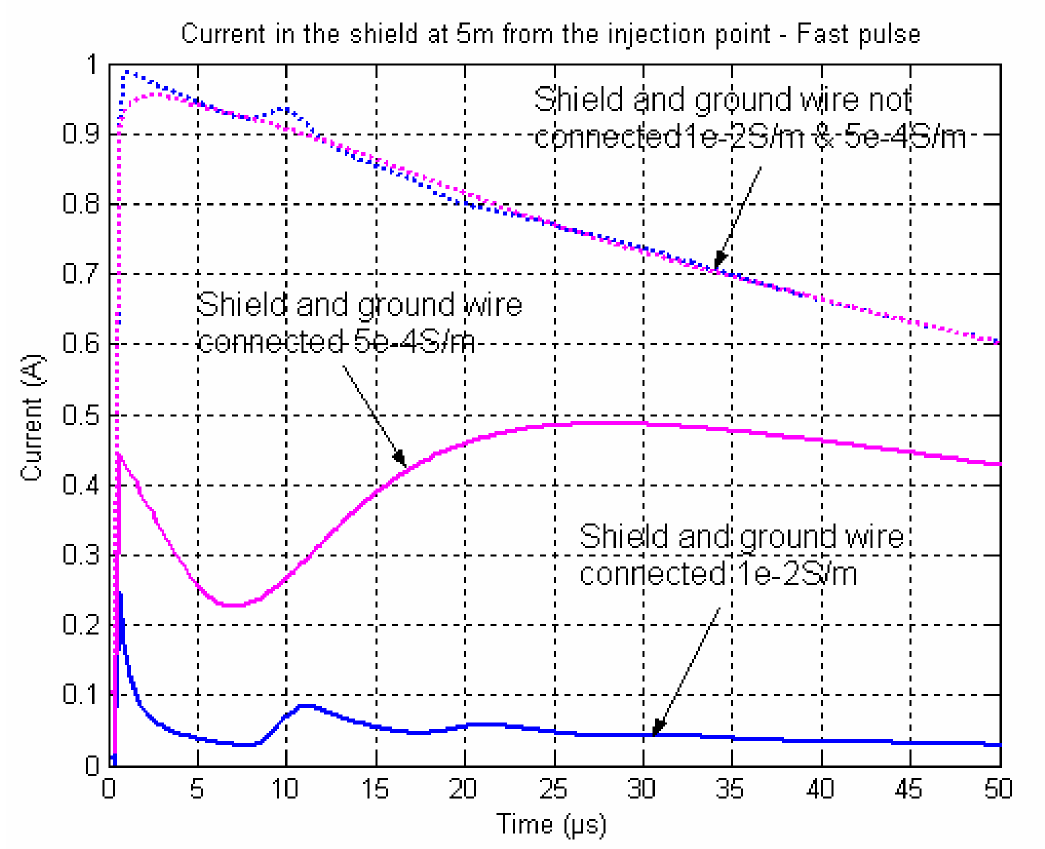

Fast pulse

Conclusions

- Tall objects experience both downward and upward flashes; the percentage of upward flashes increases with increasing structure height.
- The radiated EM fields are enhanced by the presence of the tall struck object. However, in the immediate vicinity of the tower (distances within the height structure) the electric field is reduced.
- Protecting tower complex equipments and preventing surge transfer to local community power network are not necessarily the same.   Additional measures are required to prevent surge transfer to local power network.
- Good measurement data and proven models are still needed.

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